第54卷 第2期
2016年4月

古 脊 椎 动 物 学 报
VERTEBRATA PALASIATICA

pp. 89−120
figs. 1−2

A synopsis of Paleocene stratigraphy and vertebrate paleontology in the Qianshan Basin, Anhui, China

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Abstract The Mesozoic and Cenozoic redbeds in the Qianshan Basin comprise a set of monocline clastic rocks and are subdivided into the Late Cretaceous Gaohebu Formation, the Paleocene Wanghudun Formation (including the Lower, Middle, and Upper members) and Doumu Formation (including the Lower and Upper members). Continuous investigations in the Qianshan Basin since 1970 have resulted in discovery of a lot of vertebrate specimens. Up to date, 61 species (including 9 unnamed ones) in 45 genera of vertebrates, representing reptiles, birds and mammals, have been reported from the Paleocene of the Qianshan Basin. Among them, mammals are most diverse and have been classified into 46 species (7 unnamed) of 33 genera, representing 16 families in 10 orders. According to their stratigraphic occurrence, seven fossiliferous horizons can be recognized in the Qianshan Paleocene. Based on the evidence of mammalian biostratigraphy, the strata from the Lower Member through the lower part of the Upper Member of Wanghudun Formation could be roughly correlated to the Shanghu Formation of the Nanxiong Basin (Guangdong Province) and the Shizikou Formation of the Chijiang Basin (Jiangxi Province), corresponding to the Shanghuan Asian Land Mammal Age (ALMA). Both the upper part of the Upper Member of Wanghudun Formation and the Doumu Formation could be correlated to the Nongshan Formation of the Nanxiong Basin and the Chijiang Formation of the Chijiang Basin, corresponding to the Nongshanian ALMA. Paleomagnetic results from several Chinese Paleocene basins suggest that the Shanghuan is roughly correlative to the Puercan and Torrejonian North American Land Mammal Ages (NALMA), while the Nongshanian correlative to the early to middle Tiffanian (Ti1–4a). The Shanghuan and the Nongshanian are probably correlated to the Danian and the Selandian of the Global Geologic Time Scale. Therefore, all the fossil vertebrates collected in the Qianshan Basin are the Early and Middle Paleocene in age.

Key words Qianshan, Anhui; Paleocene; vertebrates; stratigraphy; correlation

Citation Wang Y Q, Li C K, Li Q et al., 2016. A synopsis of Paleocene stratigraphy and vertebrate paleontology in the Qianshan Basin, Anhui, China. Vertebrata PalAsiatica, 54(2): 89−120

国家重点基础研究发展计划项目(编号: 2012CB821900)、国家自然科学基金(批准号: 41572013, 41572021)和财政部、国土资源部地质遗迹保护项目资助。

收稿日期：2016-03-10

1 Introduction

The Qianshan Basin, located in southwestern Anhui Province, China, is a small foreland basin on the east side of the Dabie Mountains, and comprises parts of Qianshan, Tongcheng, Taihu, Huaining, Zongyang and Lujiang counties (Chen, 1974). The basin, with northeastly extension, is about 100 km long in east-west direction and no more than 25 km in north-south direction. It is bordered by a fault northwestward with the mountainous area formed by metabolic rocks and is fulfilled by the Late Cretaceous–Paleocene fluvio-lacustrine deposits that are mainly reddish colored clastic rocks. In 1950s when the nation-wide geological survey was initiated in China, the Hefei University of Technology carried out the first investigation to the Mesozoic and Cenozoic deposits in the Qianshan Basin. Later in 1960s when they carried out geological mapping in this area, the geologists of the Geological Survey Team No. 311 of the Bureau of Geology and Mineral Resources of Anhui Province first found Paleocene vertebrates at Dinghuawu, Xiaoshi, Huaining County in 1966 (RGSBGA, 1988b). These fossil vertebrates were later identified as a turtle *Anhuichelys siaoshihensis* Yeh (1979) and an alligatorid *Eoalligator huiningensis* Young (1982). Such discovery attracted great attention of researchers from the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), the Chinese Academy of Sciences, Beijing. With the assistance of colleagues of the Geological Survey Team No. 311, the Qianshan County Museum (= former the Administrative Office of Cultural Relics of Qianshan County), and recently the Tianzhushan Global Geopark, the IVPP colleagues carried out a long term investigation that has continuously been lasting nearly half a century since 1970. Up to date, 61 species (including 9 unnamed ones) in 45 genera of Paleocene vertebrates, representing reptiles, birds and mammals, have been reported at 42 localities in the Qianshan Basin.

2 Stratigraphy

Paleocene deposits in the Qianshan Basin was first investigated by a group from the Hefei University of Technology in 1950's[1)]. They first mentioned the presence of possible Paleogene deposits, though the age determination was inferred on the basis of the nature of sedimentary rocks. The Regional Geological Survey Team No. 311 of the Bureau of Geology of Anhui Province first provided a systematic subdivision of the Paleocene in the Qianshan Basin in a report accomplished in 1970, which was later informally published (Chen,1974). Chen and Xia (1981) formally published the section measured by the geological survey team with some revisions. Their section is as follows:

1) Hefei University of Technology, 1959. Report of the geological survey in Taihu-Susong area, southeastern Dabie Mountains (1:200000).

The Wanghudun Section in the Qianshan County

Doumu Formation

14. Purplish red and very thick matrix-supported conglomerats intercalated with coarse sandstone 184.68 m
13. Grayish purple thick matrix-supported conglomerates intercalated with medium-coarse sandstone 140.22 m
12. Purplish red and thick matrix-supported conglomerates interbedded with purplish red coarse sandstone, containing fossil vertebrates: *Sinostylops promissus* Tang & Yan, *Archaeolambda tabiensis* Haung, *Heomys orientalis* Li, *Mimotona wana* Li, *Hsuiannania* sp., *Tinosaurus doumuensis* Hou, *Anhuisaurus huainanensis* Hou 117.78 m
11. Purplish red and thick conglomerate-containing medium-coarse sandstone intercalated with a few thin layers of grayish white arkose 102.58 m
10. Purplish red and thick medium-coarse sandstone interbedded with conglomerates and shales, containing fossil vertebrates: *Allictops inserrata* Qiu, *Hsiuannania tabiensis* Xu, *Mimotona robusta* Li, *Obtususdon hanhuaensis* Xu, *Agama sinensis* Hou, *Anhuicheleys tsienshanensis* Yeh 76.12 m

Wanghudun Formation

9. Purplish red and thick medium-fine sandstone intercalated with dark purple muddy shales and few thick conglomerates 157.32 m
8. Covered 307.08 m
7. Fresh purplish red and thick fine sandstone intercalated with thin arkose 179.4 m
6. Grayish purple thin to medium thick conglomerates and coarse sandstone interbedded with purplish red fine sandstone, rich in fossil vertebrates: *Anictops tabiepedis* Qiu, *Decoredon elongetus* Xu, *Diacronus anhuiensis* Xu, *D. wanghuensis* Xu, *Huaiyangale chianshanensis* Xu, *Harpyodus euros* Chiu & Li, *Mimotona wana* Li, *Mimotona* sp., *Obtusudon hanhuaensis* Xu, *Paranictops majuscula* Qiu, *Pappictidops orientalis* Chiu & Li, *Zeuctherium niteles* Tang & Yan, *Heomys* sp., *Qianshanosaurus huangpuensis* Hou 287 m

Haixingdi Formation

5. Purplish red thick medium-fine sandstone interbedded with fine muddy sandstone, intercalated with white arkose and thin conglomerates, containing fossil vertebrates: *Bemalambda* sp., *Yantanglestes convexus* Yen & Tang 496.4 m
4. Covered 27.24 m
3. Fresh purplish red thick fine sandstone, intercalated with grayish white thin feldspar and quartz sandstone, containing fossil vertebrates: *Anictops tabiepedis* Qiu, *Anchilestes* Chiu & Li, *Anaptogale wanghoensis* Xu, *Bemalambda* sp., *Wanogale hodungensis* Xu, *Chianshania gianghuaiensis* Xu, *Anqingosaurus breviocephalus* Hou 418.52 m
2. Purplish red medium-thick coarse sandstone interbedded with thin to medium-thick conglomerates 83.6 m
1. Brick red thick blocky fine sandstone, containing fossil vertebrates: primitive pantodont and lizards 268.92 m

———— conformity ————

Underlying Upper Cretaceous Gaohebu Formation

Qiu et al. (1977) redefined the Wanghudun and Doumu formations based on the investigation of the IVPP field crew. According to Qiu et al. (1977), the Wanghudun Formation, which is about 1800 m thick, overlies the Cretaceous Wanghe Formation (see discussion below) and was subdivided into the Lower, Middle, and Upper members. The Lower Member is composed of purplish red medium-fine sandstone intercalated with conglomerates and grayish white arkose sandstone. The Middle Member consists of mainly interbedded purplish red conglomerates, coarse sandstone, and fine sandstone. No fossil mammals have been recorded from this member. The Upper Member is the most fossiliferous unit in the formation, comprising purplish and brownish red fine sandstone intercalated with grayish white arkose sandstone. The Doumu Formation disconformably or conformably overlies the Wanghudun Formation and is about 600 m in total thickness. The lower part of the formation, the Lower Member, comprises thick, purplish red medium-fine sandstone intercalated with thin conglomerates and silty mudstone, while its upper part, the Upper Member, is composed of mainly interbedded thick conglomerates and sandstone (Qiu et al., 1977). Such subdivision has been widely accepted for Paleocene strata in the Qianshan Basin (e.g. Zheng and Qiu, 1979; Chow and Zheng, 1980; Li and Ting, 1983; Russell and Zhai, 1987; Wang et al., 1998).

What should be noted here is the correlation between Chen and Xia's (1981) and Qiu et al.'s (1977) subdivisions. The Lower and Middle members of Wanghudun Formation in Qiu et al.'s subdivision are roughly correlated to the Chen and Xia's Haixingdi Formation, while the Middle Member of Wanghudun Formation roughly corresponds to the upper part of Chen and Xia's Layer 5. The boundary between the Wanghudun Formation and the Doumu Formation of Qiu et al.'s subdivision is roughly located between layers 8 and 9 in Chen and Xia's. Qiu et al. (1977) adopted the Wanghe Formation from an unpublished data of the local geological survey team and used it for the underlying Late Cretaceous deposits. Later, the deposits equivalent to the Wanghe Formation was named Gaohebu Formation based on a new section with better exposures[2)] and the name was cited in some publications (e.g. Chen and Xia, 1981; RGSBGA, 1988a). Here we suggest to replace the Wanghe Formation with the Gaohebu Formation.

3 Localities of fossil vertebrates

The Paleocene deposits in the Qianshan Basin have produced a lot of fossil vertebrates at many localities. Forty two localities have been recorded in formally published references (Fig. 1). According to their stratigraphic position, these localities can be grouped in seven fossiliferous horizons recognized in the Qianshan Basin. Five of the horizons are in the Wanghudun Formation and the other two are in the Doumu Formation. The localities and fossil vertebrates therefrom are listed as follows (the original locality numbers are in brackets):

2) Regional Geological Survey of the Bureau of Geology of Anhui Province, 1974. Report of the regional geological survey: Liu'an and Yuexi (1:200000).

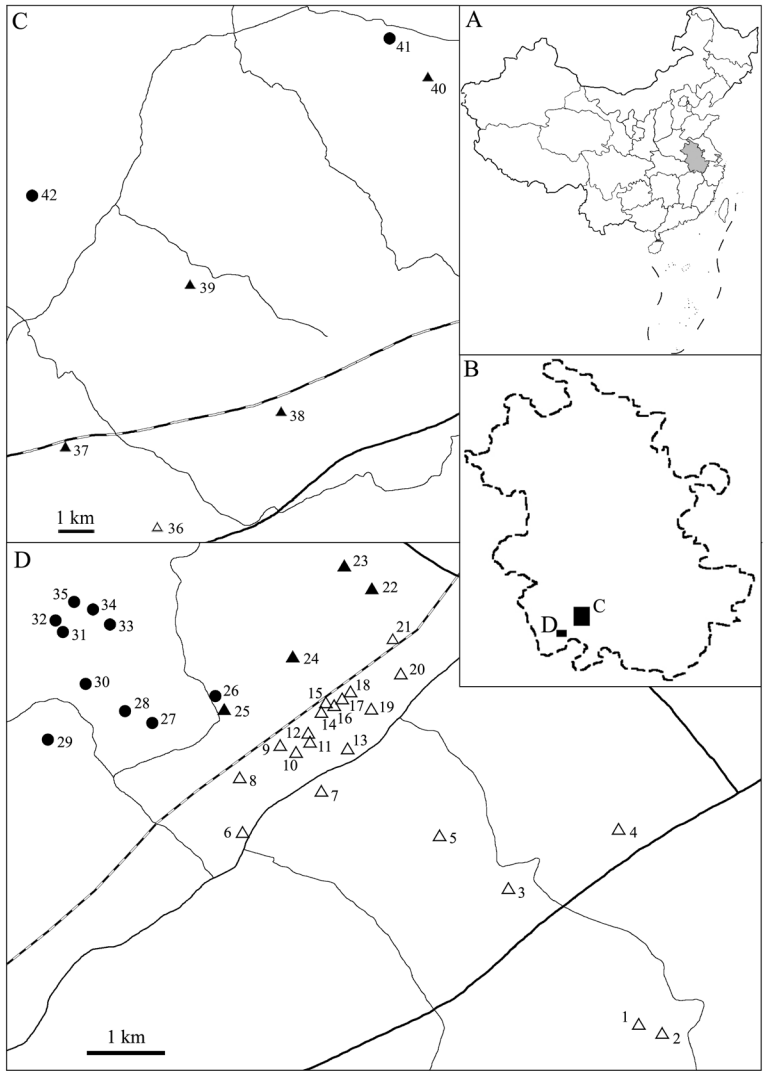

Fig. 1 Localities of Paleocene vertebrates in the Qianshan Basin, Anhui Province, China

A. A sketch map showing the general location of Anhui Province (shaded) in China; B. A map of Anhui Province showing the location of boxes C and D; C, D. More detailed maps showing the Paleocene vertebrate localities in the Qianshan Basin.

Open symbols refer to the Shanghuan localities, while solid ones for the Nongshanian localities. Triangles and circles refer to the localities in the Wanghudun and the Doumu formations, respectively.

1. Haixingdi (71002); 2. Fanglaowu (71003); 3. Wangdawu (71001); 4. Wanhuawu (71005); 5. Chidoukan (71006); 6. Dingxiawu (70020); 7. Zhangchong; 8. Sanliantang (70023); 9. Zhongjialaowu; 10. Taowu (70022); 11. Yangwu Southwest (71014); 12. Yangwu West (71019); 13. Lijialaowu (70021); 14. Shangxialou (71016); 15. Zhangjiawu Southwest (71010); 16. Zhangjiawu South (71008); 17. Zhangjiawu Southeast (71011); 18. Zhangjiawu East (71009); 19. Zhangxinwu (71007); 20. Wanghudun Northeast; 21. Chenxiawu (71012); 22. Lianhuatang Southeast; 23. Lianhuatang; 24. Fujiashanzui; 25. Xudawu South; 26. Xudawu; 27. Hanhuawu South (71079); 28. Hanhuawu West (71020); 29. Hanxindongwu (71015); 30. Hanjiashanbao; 31. Chongliwu (71018); 32. Zhugongtang West; 33. Meiyuan; 34. Yangxiaowu (71017); 35. Yangxinwu (71071); 36. Dinghuawu (71080); 37. Chenjiachuanmenkou; 38. Mao'an (71075); 39. Jinshi; 40. Wangjiazha; 41. Huanghetang Reservoir; 42. Yanglaowu

(1) Localities in the basal part of the Lower Member of Wanghudun Formation

Two localities are in this horizon, and represent the lowest vertebrate-bearing bed in the Qianshan Paleocene.

Haixingdi (71002): Bemalambdidae gen. et sp. indet., *Qianshanosaurus huangpuensis* Hou, 1974

Fanglaowu (71003): *Astigale wanensis* Zhang & Tong, 1981, *Benaius qianshuiensis* Wang & Jin, 2004

(2) Localities in the middle part of the Lower Member of Wanghudun Formation

Three localities are included in this horizon. Two of them, Wangdawu and Wanhuawu, are close to the main section, their inclusion is thus credible. Another locality, Dinghuahu, is somewhat far from the main section. Its geographic position and lithologic feature show the possibility in correlation with the other two localities.

Wangdawu (71001): *Wanogale hodungensis* Xu, 1976, *Chianshania gianghuaiensis* Xu, 1976, *Anaptogale wanghoensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Anchilestes impolitus* Chiu & Li, 1977, *Plethorodon chienshanensis* Huang & Zheng, 1987, *Bemalambda* sp., *Anqingosaurus brevicephalus* Hou, 1976, *Changjiangosaurus huananensis* Hou, 1976

Wanhuawu (71005): *Carticops canina* Ding & Tong, 1979

Dinghuawu (71080): *Anhuichelys siaoshihensis* Yeh, 1979, *Eoalligator huiningensis* Young, 1982

(3) Localities in the upper part of the Lower Member of Wanghudun Formation

Only one locality with fossil vertebrates reported can be referred to this horizon.

Chidoukan (71006): *Yantanglestes conexus* (Yan & Tang, 1976), *Bemalambda* sp., *Carticops canina* Ding & Tong, 1979

(4) Localities in the lower part of the Upper Member of Wanghudun Formation

This horizon is most fossiliferous in the Qianshan Paleocene. A number of localities were discovered in the horizon. All the localities are near the main section, and their inclusion in the horizon is fairly certain.

Lijialaowu (70021): *Anictops tabiepedis* Qiu, 1977, *A. wanghudunensis* Zheng et al., 1999, *Pappictidops orientalis* Chiu & Li, 1977, *Qianshanosaurus huangpuensis* Hou, 1974, *Qianshanornis rapax* Mayr et al., 2013

Zhangxinwu (71007): *Anictops tabiepedis* Qiu, 1977

Wanghudun Northeast: *Paranictops* aff. *P. maiuscula*

Dingxiawu (70020): *Huaiyangale chianshanensis* Xu, 1976, *Huaiyangale* sp., *Anictops tabiepedis* Qiu, 1977, *Obtususdon hanhuaensis* Xu, 1977

Zhangjiawu East (71009): *Huaiyangale chianshanensis* Xu, 1976, *Diacronus anhuiensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Zeuctherium niteles* Tang & Yan, 1976, *Decoredon elongetus* Xu, 1977, *Anhuichelys siaoshihensis* Yeh, 1979

Zhangjiawu Southeast (71011): *Anictops tabiepedis* Qiu, 1977

Zhangjiawu South (71008): *Anictops tabiepedis* Qiu, 1977, *Mimotona lii* Dashzeveg & Russell, 1988, *Pappictidops orientalis* Chiu & Li, 1977

Zhangjiawu Southwest (71010): *Paranictops maiuscula* Qiu, 1977, *Heomys* sp.

Shangxialou (71016): *Diacronus wanghuensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Mimotona*

wana Li, 1977, ?*Altilambda tenuis* Chow & Wang, 1978

Chenxiawu (71012): *Anictops tabiepedis* Qiu, 1977, *Harpyodus euros* Chiu & Li, 1977

Zhangchong: *Anhuichelys siaoshihensis* Yeh, 1979

Yangwu Southwest (71014): ?*Paranictops* sp.

Yangwu West (71019): *Anictops tabiepedis* Qiu, 1977

Taowu (70022): *Anictops tabiepedis* Qiu, 1977, *Anictops* aff. *A. tabiepedis*, *Paranictops majuscula* Qiu, 1977

Sanliantang (70023): *Wania chowi* Wang, 1995, *Bemalambda* sp. cf. *B. crassa* Chow et al., 1973

Zhongjialaowu: *Archaeoryctes wangi* Missiaen et al., 2013

(5) Localities in the upper part of the Upper Member of Wanghudun Formation

Eight localities are included in this horizon. Four of them, Fujiashanzui, Lianhuatang Southeast, Lianhuatang, and Xudawu South, are close to the main section and can be referred to the horizon with certainty. However, the other four localities, Chenjiachuanmenkou, Mao'an, Jinshi, and Wangjiazha, are less certain to be included in the horizon, because they are in some distance from the main section. They are referred to the horizon mainly based on the biostratigraphic data.

Fujiashanzui: *Eosigale yujingensis* Hu, 1993, *Mina hui* Li et al., 2016, *Anhuichelys tsienshanensis* Yeh, 1979

Lianhuatang Southeast: *Simplodon qianshanensis* Huang & Zheng, 2003

Lianhuatang: *Anhuichelys tsienshanensis* Yeh, 1979

Xudawu South: *Qipania yui* Hu, 1993

Chenjiachuanmenkou: *Altilambda yujingensis* Wang et al., 1992

Mao'an (71075): *Altilambda pactus* Chow & Wang, 1978

Jinshi: *Anhuichelys tsienshanensis* Yeh, 1979

Wangjiazha: *Anhuichelys tsienshanensis* Yeh, 1979

(6) Localities in the Lower Member of Doumu Formation

Among the fossil localities listed below, the first five can be included in the horizon with certainty, since they are near the main section. The last one is tentatively included in the horizon, mainly based on the lithological features, because the only reported vertebrate fossil is a calcaneus of Glires that cannot be currently identified at lower taxonomic level (Zhang et al., 2016).

Xudawu: *Anhuichelys tsienshanensis* Yeh, 1979

Hanhuawu South (71079): *Hsiuannania tabiensis* Xu, 1976, *Allictops inserrata* Qiu, 1977, *Mimotona robusta* Li, 1977, *Obtususdon hanhuaensis* Xu, 1977, *Agama sinensis* Hou, 1974, *Anhuichelys tsienshanensis* Yeh, 1979

Hanxindongwu (71015): *Allictops inserrata* Qiu, 1977

Hanhuawu West (71020): *Anhuichelys tsienshanensis* Yeh, 1979

Hanjiashanbao: *Anhuichelys tsienshanensis* Yeh, 1979

Huanghetang Reservoir: Glires gen. et sp. indet.

(7) Localities in the Upper Member of Doumu Formation

Among the six localities listed below, only Yanglaowu is not near the main section. The lithology of the deposits and fossil turtle together with the geographic location clearly show that it should be in this horizon.

Yangxiaowu (71017): *Hsiuannania* sp., *Heomys orientalis* Li, 1977, *Mimotona wana* Li, 1977, *Hyracolestes ermineus* Matthew & Granger, 1925, *Wanolestes lii* Huang & Zheng, 2002, *Sinostylops promissus* Tang & Yan, 1976, *Archaeolambda tabiensis* Huang, 1977, *Anhuisaurus huainanensis* Hou, 1974, Varaniformes gen. et sp. indet., *Anhuichelys tsienshanensis* Yeh, 1979, *A. doumuensis* Tong et al., 2016

Chongliwu (71018): *Tinosaurus doumuensis* Hou, 1974

Yangxinwu (71071): *Anhuichelys doumuensis* Tong et al., 2016

Zhugongtang West: *Wanshuina lii* Hou, 1994

Meiyuan: *Anhuichelys doumuensis* Tong et al., 2016

Yanglaowu: *Anhuichelys doumuensis* Tong et al., 2016

4 Fossil vertebrates

From the above mentioned localities, different kinds of fossil vertebrates have been found during the past half a century. Up to date, 52 species plus 9 unnamed ones of reptiles, birds, and mammals were reported from the Paleocene of the Qianshan Basin. A complete faunal list of fossil vertebrates reported from the Paleocene of the Qianshan Basin is provided in Appendix 1.

4.1 Reptilia

The reptilian fossils recovered from the Qianshan Paleocene represent three major groups, Testudines, Squamata, and Crocodilia.

4.1.1 Testudines

Fossil turtles are relatively common in the Qianshan Basin, and have been found in many localities (for details, see Tong et al., 2016). All the specimens were referred to a single genus *Anhuichelys* Yeh, 1979. When Yeh (1979) first reported the fossil turtles of the basin, he referred *Anhuichelys* to Emydidae, with two new species, *A. siaoshihensis* and *A. tsienshanensis*, and an unnamed species, *Anhuichelys* sp. After that, a number of additional specimens were collected by the colleagues of the Qianshan County Museum, but no further research has been done, except Chen (1983) described a new species of *Anhuichelys*, *A. xinzhouensis*, from the Paleocene deposits of the Xinzhou Basin, Hubei Province.

Recently, Tong et al. (2016) comprehensively studied all the available specimens of Paleocene turtles from both the Qianshan and Xinzhou basins. In addition to referring some

new specimens to *A. siaoshihensis* and *A. tsienshanensis*, they synonymized *A. xinzhouensis* with *A. tsienshanensis*, and named a new species, *A. doumuensis*, using the specimen of Yeh's *Anhuichelys* sp. as the holotype. Meanwhile, they described four specimens under an unnamed species, *Anhuichelys* sp. Based on these materials, Tong and her colleagues conducted a phylogenetic analysis. Their result suggests that *Anhuichelys* is a member of the stem Testudinidae. "*Anhuichelys* is likely a land turtle and also the first testudinoid to develop the hinge on the shell" (Tong et al., 2016).

According to the current stratigraphical information, specimens of *Anhuichelys siaoshihensis* were found from the Lower Member and the lower part of the Upper Member of the Wanghudun Formation; *A. tsienshanensis* specimens were collected from the upper part of the Upper Member of the Wanghudun Formation through the Upper Member of the Doumu Formation; *A. doumuensis* is only present in the Upper Member of the Doumu Formation; and *Anhuichelys* sp. was from the upper part of the Upper Member of the Wanghudun Formation and possibly the Lower Member of the Doumu Formation. The occurrence of fossil turtles in the Qianshan Basin shows clearly the biostratigraphical significance. *A. siaoshihensis* is a turtle member of the Shanghuan Asian Land Mammal Age (ALMA) that is Early Paleocene in age and can be correlated to both the Puercan and Torrejonian North American Land Mammal Ages (NALMA). All the other three species are the members of the Nongshanian ALMA that is Middle Paleocene in age and can be correlated to early–middle Tiffanian NALMA (see further discussion below).

4.1.2 Squamata

The fossil lizards from the Paleocene of Qianshan Basin were first reported by Hou (1974). He named two new genera and four new species, *Qianshanosaurus huangpuensis*, *Anhuisaurus huainanensis*, *Tinosaurus doumuensis*, and *Agama sinensis*, and referred *Q. huangpuensis* to Iquanidae and the other three to Agamidae (Hou, 1974). Two years later, Hou (1976) described two new genera and species, *Anqingosaurus brevicephalus* and *Changjiangosaurus huananensis*, and referred them to Chamaelenantidae and Changjiangosauridae respectively. The systematic position of these lizard taxa has been long debated (for details, refer to Dong et al., 2016). Dong et al. (2016) reexamined all the reported lizard specimens from the Paleocene of the Qianshan Basin and revised their taxonomic position. Under the current classification of Squamata, they referred *Agama sinensis* (nomen dubium), *Qianshanosaurus huangpuensis*, and *Tinosaurus doumuensis* to Acrodonta, and considered *Anhuisaurus huainanensis*, *Anqingosaurus brevicephalus*, and *Changjiangosaurus huananensis* as Squamata *incertae sedis* (Dong et al., 2016). In addition, they recognized the first varaniform from the Qianshan Paleocene that were represented by a nearly complete right dentary, a series of six articulated vertebrae, and a sacrum with the last presacral (Dong et al., 2016), which were originally identified as *Anhuisaurus huainanensis* (Hou, 1974).

According to the stratigraphical information, *Anqingosaurus brevicephalus* and

Changjiangosaurus huananensis were collected from the Lower Member of Wanghudun Formation, and *Qianshanosaurus huangpuensis* was found in both the Lower Member and the lower part of the Upper Member of Wanghudun Formation. These three taxa represent the squamate members of the Early Paleocene Shanghuan ALMA. *Agama sinensis* was only reported from the Lower Member of the Doumu Formation (recorded as Wanghudun Formation by mistake in the original report, i.e. Hou, 1974:199). *Tinosaurus doumuensis*, *Anhuisaurus huainanensis*, and Varaniformes gen. et sp. indet. were all from the Upper Member of the Doumu Formation. These four taxa are squamate representatives of the Middle Paleocene Nongshanian ALMA. Readers can refer to Dong et al. (2016) for detailed information about the lizard-bearing localities.

4.1.3 Crocodilia

The first crocodilian fossil from the Qianshan Paleocene deposits was found by the geological survey team at Dinghuawu, Huaining County in 1966 (RGSBGA, 1988b). It was not formally described until 1982 when Young (1982) named it *Eoalligator huiningensis*. The species was originally referred to Alligatorinae (Young, 1982), which was later questioned (Whiting and Hastings, 2015). Here we follow Young (1982) and list *E. huiningensis* as a member of Alligatorinae, before its taxonomic position is restudied.

Another crocodilian was reported by Zhang (1981). It was possibly collected from the Paleocene of the Qianshan Basin. Zhang (1981) named it *Wanosuchus atresus* within its own family, Wanosuchidae.

Eoalligator huiningensis was from the Lower Member of the Wanghudun Formation at Dinghuawu (Qiu et al., 1977), which is Early Paleocene Shanghuan in age (see discussion below). However, the locality and horizon of *Wanosuchus atresus* remains unknown.

4.2 Aves

Two fossil birds have been reported from the Qianshan Paleocene. *Wanshuina lii* was represented by the shaft of a right humerus, the distal end of a left tibiotarsus, and the associated left tarsometatarsus lacking distal end, and was originally referred to Rallidae (Hou, 1994). It was later considered to have some similarities to *Walbeckornis* from the Paleocene of Germany (Mayr, 2009; Mayr et al., 2013). Since further examination is required to clarify its taxonomic position, we tentatively follow Hou (1994) to list *W. lii* as a member of Rallidae. Another fossil bird, *Qianshanornis rapax*, was considered similar to *Strigogyps* and assigned to its own family Qianshanornithidae (Mayr et al., 2013).

Wanshuina lii was collected from the Upper Member of the Doumu Formation at Zhugongtang West, which is considered to be the deposits of the Nongshanian ALMA. The specimens of *Qianshanornis rapax* were found from the lower part of the Upper Member of the Wanghudun Formation at Lijialaowu (Mayr et al., 2013), which is considered to be the Shanghuan ALMA (see discussion below).

4.3 Mammalia

Fossil mammals are relatively common and highly diverse in the Paleocene deposits of the Qianshan Basin. Up to date, twenty eight localities have been reported to produce fossil mammals. These fossils form the Qianshan Paleocene mammal fauna that comprises 39 named species together with eight indeterminate ones.

4.3.1 Anagalida

Anagalida, an Asian endemic mammalian group, has the most diverse record among the Paleocene mammals reported in the Qianshan Basin. Three families, Anagalidae, Pseudictopidae and Astigalidae, have been found there.

Anagalidae Qianshan Paleocene anagalids were first reported by Xu (1976). He described seven species and two unnamed ones of six genera: *Huaiyangale chianshanensis*, *Huaiyangale* sp., *Hsiuannania tabiensis*, *Hsiuannania* sp., *Wanogale hodungensis*, *Chianshania gianghuaiensis*, *Diacronus wanghuensis*, *D. anhuiensis*, and *Anaptogale wanghoensis*. He assigned *Huaiyangale* and *Hsiuannania* to Anagalidae, while tentatively referred the other four genera to the same family (Xu, 1976).

Hu (1993) reported two new genera and species, *Eosigale gujingensis* and *Qipania yui*, based on so far the best preserved anagalid material from the Qianshan Basin. He also discussed the phylogenetic relationships of Anagalidae. As a result of the phylogenetic analysis, he confirmed the attribution to Anagalidae of *Huaiyangale*, *Eosigale*, *Qipania*, and *Hsiuannania* and tentatively referred *Diacronus* and *Anaptogale* to the family. In addition, he assigned *Chianshania* to Astigalidae and considered *Wanogale* to be a member of family indet. (Hu, 1993).

Szalay and Li (1986) combined *Diacronus anhuiensis* Xu (1976) with *Decoredon elongetus* Xu (1977) into a single species, *Decoredon anhuiensis*, and proposed it as “the oldest recognized member of euprimates, either an omomyid or a member of the common stock which gave rise to Adapidae and Omomyidae” (Szalay and Li, 1986:387). This assignment has received little support (Rose, 1994) and was considered to be questionable (Rose et al., 1994) or unlikely (Gingerich et al., 1991). Because of the conspecific assignment suspect of the holotypes (and only known specimens) of both taxa (Rose et al., 1994), it might better consider them as separate species and tentatively assign *Diacronus anhuiensis* to Anagalidae at present.

Anaptogale and *Wanogale* were collected from the Lower Member of the Wanghudun Formation, and both *Huaiyangale* and *Diacronus* were discovered from the lower part of the Upper Member of the Wanghudun Formation. According to the current information, these four genera are members of Early Paleocene Shanghuan ALMA. Both *Eosigale* and *Qipania* were found from the upper part of the Upper Member of the Wanghudun Formation, and *Hsiuannania* was from the Doumu Formation. They are anagalid representatives of Middle Paleocene Nongshanian ALMA. Locality information of fossil anagalids in the Qianshan Basin can be found in Xu (1976) and Hu (1993).

Pseudictopidae Pseudictopids are also common in the Paleocene of the Qianshan Basin. Qiu (1977) made a relatively comprehensive study on pseudictopids on the basis of available materials by then. He described three new species of three new genera as well as one unnamed and one affinis species: *Anictops tabiepedis*, *Anictops* aff. *A. tabiepedis*, *Paranictops majuscule*, *Paranictops* sp., and *Allictops inserrata*. Two years later, Ding and Tong (1979) named *Cartictops canina* based on an anterior portion of left lower jaw (IVPP V 4307) that was referred to *Paranictops* sp. by Qiu (1977) and a left m2 or m1 (IVPP V 4318) that was described as indeterminate genus and species by Chiu and Li (1977). Zheng et al. (1999) reported some new specimens from the Qianshan Paleocene. They named a new species, *Anictops wanghudunensis*, and referred the rest specimens to *Anictops tabiepedis* and *Paranictops* aff. *P. majuscule*, respectively.

Cartictops and *Paranictops* were collected from the Lower Member and the lower part of the Upper Member of Wanghudun Formation, respectively, and *Anictops* was found from both horizons. They are representatives of the Early Paleocene Shanghuan pseudictopids. *Allictops*, from the Lower Member of Doumu Formation, represents the only pseudictopid form of the Middle Paleocene Nongshanian ALMA in the Qianshan Basin.

Astigalidae Up to date, two species of Astigalidae have been reported from the Qianshan Paleocene. *Astigale wanensis* was named by Zhang and Tong (1981) based on a right lower jaw found at Fanglaowu. *Chianshania gianghuaiensis*, collected at Wangdawu, was originally assigned to Anagalidae (Xu, 1976), but was later considered to be a member of Astigalidae (Hu, 1993). Both taxa were collected from the Lower Member of Wanghudun Formation, and are of Early Paleocene Shanghuan ALMA.

4.3.2 Simplicidentata

Fossil simplicidentates from the Qianshan Basin were represented by some eurymylids. Li (1977) first reported *Heomys orientalis* and clearly pointed out that *Heomys* is a remote ancestor form of rodents, based on its similarities to primitive rodents. Such opinion received new evidence from the further examination on the materials of *Heomys* and primitive rodents (Dawson et al., 1984; Li et al., 1987; Li and Ting, 1985, 1993; Li and Chow, 1994) and was supported by studies on related forms (Meng and Wyss, 1994, 2001; Meng et al., 1994b, 2003). Some researchers even considered *Heomys* as primitive rodents (Flynn, 1994; McKenna and Bell, 1997), but recent phylogenetic analysis did not suggest that *Heomys* has a closer relationship with typical rodents than the other eurymylids do (Meng and Wyss, 2001; Meng et al., 2003; Meng, 2004). Currently, it might be better to assigned *Heomys* as a member of Eurymylidae. In addition, Li (1977) identified the poorly preserved anterior portion of a skull as *Heomys* sp.

Heomys orientalis was collected from the Upper Member of Doumu Formation at Yangxiaowu (Li, 1977). It is a representative of the Middle Paleocene Nongshanian ALMA. *Heomys* sp. was found from the lower part of the Upper Member of Wanghudun Formation

at Zhangjiawu Southwest. It represents a eurymylid record in the Early Paleocene Shanghuan ALMA.

4.3.3 Mimotonida

Mimotonida was proposed by Li et al. (1987) to include the basal Glires that have two pairs of incisors in both upper and lower dentitions. Although some recent phylogenetic analyses showed that Mimotonida is a paraphyletic group (Meng and Wyss, 2001; Meng, 2004; Asher et al., 2005), it may be convenient to keep using Mimotonida until a better phylogenetic relationship of the basal Glires becomes available (Li et al., 2016). Two genera of mimotonidans, *Mimotona* and *Mina*, have been reported from the Qianshan Basin and represent two different families, Mimotonidae and Mimolagidae (Li, 1977; Li et al., 2016).

Mimotonidae Li (1977) proposed Mimotonidae to include only the type genus, *Mimotona*, but several genera were referred to the family later (for details, see Li et al., 2016). With the new data being accumulated, it becomes more likely that Mimotonidae is a monophyletic group only containing *Mimotona* (Li et al., 2016).

When he first reported the fossil mimotonids from the Qianshan Paleocene, Li (1977) described two named and one unnamed species of *Mimotona*, *M. wana*, *M. robusta*, and *Mimotona* sp. He also noticed the difference of *Mimotona* sp. from the other two species and mentioned that it might represent a new species, but it was not formally named until Dashzeveg and Russell (1988) named it *M. lii*.

The holotype and referred two left lower molars of *Mimotona wana* were found from the Upper Member of Doumu Formation at Yangxiaowu (Li, 1977). The type and only specimen of *M. robusta* was from the Lower Member of Doumu Formation at Hanhuawu South. Biostratigraphic correlation indicates both are in the Nongshanian ALMA, Middle Paleocene in age. The type and only specimen of *M. lii* was collected from the lower part of Upper Member of Wanghudun Formation at Zhangjiawu South. Its stratigraphic level is in the Early Paleocene Shanghuan ALMA. A right premaxilla with alveoli for I2-3 (IVPP V 4326) from the lower part of the Upper Member of Wanghudun Formation at Shangxialou was referred to *M. wana* as paratype (Li, 1977), but the recent discovery of *Mina hui* (Li et al., 2016) may raise the doubt about its assignment to *Mimotona*. The occurrence of *M. wana* in Early Paleocene thus requires further evidence.

Mimolagidae In the Qianshan Basin, Mimolagidae was represented by a recently reported basal duplicidentate *Mina hui*. The type specimens, found from the upper part of the Upper Member of Wanghudun Formation at Fujiashanzui, include a partial right rostrum with dI2 and I3 and a fragmentary left maxilla with M1, M2 and alveoli of P2-4 (IVPP V 7509) (Li et al., 2016). It is a member of Qianshan mammals of the Middle Paleocene Nongshanian ALMA.

4.3.4 Mesonychia

Mesonychia was represented by a single species of Mesonychidae in the Qianshan Basin. Yan and Tang (1976) reported the only mesonychid of the Qianshan Paleocene and named it *Lestes conexus*. The genus name was later replaced with *Yantanglestes* because *Lestes* was preoccupied by a zygopteran insect (Ideker and Yan, 1980). *Yantanglestes conexus* was collected from the Lower Member of Wanghudun Formation at Chidoukan (originally called 150 meters northwest of Jiangjiawu) (Yan and Tang, 1976; Qiu et al., 1977). The fossil-bearing level at this locality can be assigned to the Early Paleocene Shanghuan ALMA.

4.3.5 Pantodonta

Pantodonta is one of the most common mammalian groups in the Chinese Paleocene. Four families, Bemalambdidae, Harpyodidae, Pantolambdodontidae and Pastoralodontidae, have been recorded in the Qianshan Basin. All of them are Asian endemic forms.

Bemalambdidae Compared to the fossil bemalambdids from the contemporaneous Nanxiong and Chijiang basins in southern China, specimens of Bemalambdidae found in the Qianshan Basin are much less and poorly preserved. The reported Qianshan Paleocene bemalambdids, *Bemalambda* sp. and Bemalambdidae gen. et sp. indet., were represented by fragmentary material and were not able to be further identified (Huang, 1978). Both taxa were found from the Lower Member of Wanghudun Formation. The specimens referred to *Bemalambda* sp. were collected at Chidoukan and Wangdawu, which are stratigraphically higher than Haixingdi where Bemalambdidae gen. et sp. indet. was discovered. The strata producing both taxa can be assigned to the Early Paleocene Shanghuan ALMA.

Harpyodidae Chiu and Li (1977) named *Harpyodus euros* based on a fragmentary left maxilla with M1–3 and referred it to an indeterminate family of Deltatheridia Van Valen, 1966. Two years later, Wang (1979) proposed Harpyodidae for the genus and suggested its pantodont affinities, when she described a new species of *Harpyodus* from the upper part of the Lannikeng Member of Chijiang Formation in the Chijiang Basin, Jiangxi, southern China. The assignment of *Harpyodus* to Pantodonta has been widely accepted (e.g. de Muizon and Marshall, 1992; McKenna and Bell, 1997; Wang et al., 1998; de Muizon et al., 2015).

Harpyodus euros was found from the lower part of the Upper Member of Wanghudun Formation at Chenxiawu (Chiu and Li, 1977), which is within the Early Paleocene Shanghuan ALMA.

Pantolambdodontidae The only pantolambdodontid from the Qianshan Basin is represented by *Archaeolambda tabiensis*. It was reported by Huang (1977) based on a nearly completed skeleton that is so far the only known skeleton of the genus and family. Huang (1977) referred *A. tabiensis* to Archaeolambdidae, but noted the possibility of synomizing Archaeolambdidae with Pantolambdodontidae. Chow and Qi (1978) pointed out that *Pantolambdodon* and *Archaeolambda* obviously belong to one family, and all the taxa previously referred to Archaeolambdidae should be reassigned to Pantolambdodontidae.

Such opinion was accepted by the latter researchers (e.g. Huang, 1995; Huang and Chen, 1997; Huang and Zheng, 1997, 2003b; McKenna and Bell, 1997; Tong and Wang, 2006). The specimen of *A. tabiensis* was collected from the Upper Member of Doumu Formation at Yangxiaowu (Huang, 1977). It is considered to be the Middle Paleocene Nongshanian ALMA.

Pastoralodontidae Pastoralodontids are the most common pantodonts in the Qianshan Paleocene. They are represented by three species of one genus, *Altilambda pactus*, *A. tenuis*, and *A. yujingensis* (Chow and Wang, 1978; Wang et al., 1992). The specimens of *A. tenuis* (two fragmentary lower jaws) are not well-preserved, and their assignment to *Altilambda* remains somehow questionable. All the three species were found from the Upper Member of Wanghudun Formation. ?*A. tenuis* was collected from the lower part of the Upper Member of Wanghudun Formation at Shangxialou (Chow and Wang, 1978). It is an Early Paleocene Shanghuan mammal. The other two species, discovered respectively at Mao'an and Chenjiachuanmenkou, are morphologically more derived than ?*A. tenuis*. They may be stratigraphically higher than ?*A. tenuis* and are possibly of the Middle Paleocene Nongshanian ALMA.

4.3.6 Tillodontia

Three mammalian genera and species, reported from the Qianshan Basin, can be referred to Tillodontia (Wang and Jin, 2004). *Plethorodon chienshanensis* was described by Huang and Zheng (1987) based on a partial skull with complete cheek tooth dentition of both sides. *P. chienshanensis* was tentatively assigned to the order Pantodonta under its own family Plethorodontidae in the original paper (Huang and Zheng, 1987). Later, de Muizon and Marshall (1992) considered it to be a tillodont instead of a pantodont. This opinion was followed by McKenna and Bell (1997) and Wang et al. (1998), but disputed by Ting (1998) and Tong et al. (2003). However, after a detailed comparison and a phylogenetic analysis, Wang and Jin (2004) considered *P. chienshanensis* to be a tillodont.

Huang and Zheng (2003a) named another tillodont, *Simplodon qianshanensis*, on the basis of a right maxilla with P3–M3, and questionably referred it to Esthonychidae. *Simplodon* has some similarities to tillodonts, but no sufficient evidence supports its assignment to Esthonychidae. It might be reasonable to refer *Simplodon* to indeterminate family of Tillodontia.

Wang and Jin (2004) described a left lower jaw with c–m3 from the Paleocene of the Qianshan Basin and named it *Benaius qianshuiensis*. The species was classified as a tillodont but not assigned to a special family.

Both *Plethorodon chienshanensis* and *Benaius qianshuiensis* were collected from the Lower Member of Wanghudun Formation at Wangdawu and Fanglaowu respectively (Huang and Zheng, 1987; Wang and Jin, 2004). The Wangdawu locality is stratigraphically higher than the Fanglaowu laocality, but they both are in the Early Paleocene Shanghuan ALMA. *Simplodon qianshanensis* was found from the upper part of the Upper Member of Wanghudun

Formation southeast to Lianhuatang (Huang and Zheng, 2003a). It is a member of the Middle Paleocene Nongshanian mammals.

4.3.7 Arctostylopida

Arctostylopida contains only one family Arctostylopidae (Cifelli and Schaff, 1998). Fossil arctostylopids were originally thought to have close relationships to the South American notoungulates (Matthew, 1915) and had been referred to the family Arctostylopidae of the order Notoungulata for many years (Schlosser, 1923; Matthew and Granger, 1925; Matthew et al., 1929; Patterson, 1934; Tang and Yan, 1976; Chow and Qi, 1978; Zheng, 1979; Rose, 1981; Gingerich, 1985; Zheng and Huang, 1986; Nessov, 1987; Huang and Chen, 1997). Cifelli et al. (1989) considered that Arctostylopidae was not related to Notoungulata and proposed a new order, Arctostylopida, for the family. This opinion has been widely accepted (e.g. McKenna and Bell, 1997; Huang and Zheng, 1997, 2003b; Huang et al., 2001; Kondrashov and Lucas, 2004a; Zack, 2004; Tong and Wang, 2006; Missiaen and Smith, 2008; Secord, 2008; Wang et al., 2008; Missiaen et al., 2012).

Only one arctostylopid species, *Sinostylops promissus*, has been reported from the Upper Member of Doumu Formation at Yangxiaowu, Qianshan (Tang and Yan, 1976). It is of the Middle Paleocene Nongshanian ALMA.

4.3.8 Carnivora

The only species of Carnivora, *Pappictidops orientalis*, was described by Chiu and Li (1977). The specimens include a right maxilla with canine and P2–M2 (holotype), and the horizontal ramus of a juvenile left lower jaw (referred specimen). *Pappictidops* was originally referred to the Viverravinae of Miacidae (Chiu and Li, 1977). It was considered to be most similar to North American Paleocene *Ictidopappus* (Chiu and Li, 1977; Wang, 1978). Flynn and Galiano (1982) resurrected the family Viverravidae Wortman & Matthew, 1899 and it has been widely used (e.g. Eaton, 1985; Gingerich and Winkler, 1985; Gingerich, 1989; Gunnell et al., 1992; Polly, 1997; Gunnell, 1998; Eberle and McKenna, 2002; Meehan and Wilson, 2002; Huang and Zheng, 2005; Gingerich and Smith, 2006; Tong and Wang, 2006; Beard and Dawson, 2009; Friscia and Rassmussen, 2010; Scott et al., 2013). It is reliable to assign *Pappictidops* together with *Ictidopappus* to Viverravidae. A couple of papers mentioned that the Asian viverravid *Pappictidops* was recorded in Late Paleocene and earliest Eocene (Gingerich and Winkler, 1985; Polly, 1997), but this genus has only been found in the Paleocene of both Qianshan and Nanxiong basins (Chiu and Li, 1977; Wang, 1978). The specimens of Qianshan *Pappictidops* were discovered from the lower part of the Upper Member of Wanghudun Formation at Zhangjiawu and Lijialaowu respectively (Chiu and Li, 1977), which is of the Early Paleocene Shanghuan ALMA.

4.3.9 Cimolesta

Chiu and Li (1977) described a fragmentary right lower jaw with p3–m1 and identified as *Hyracolestes ermineus* under Deltatheridia. *H. ermineus* was first named from the Paleocene of Mongolia and questionably referred to Creodonta by Matthew and Granger (1925). Van Valen (1966) placed it in Erinaceoidea of Insectivora, while Szalay and McKenna (1971) referred it to Deltatheridiidae of Insectivora. McKenna et al. (1984) moved *H. ermineus* to Micropternodontidae of Soricomorpha. Currently, *Hyracolestes* is included in Sarcodontidae of the mirorder Cimolesta (Lopatin and Kondrashov, 2004; Missiaen and Smith, 2008).

The species was found from the Upper Member of Doumu Formation at Yangxiaowu, which is in the Middle Paleocene Nongshanian ALMA.

4.3.10 Didymoconida

The taxonomic position of Didymoconidae varies greatly. It has been placed in different orders, e.g. Insectivora (Meng et al., 1994a; Wang et al., 2001), Deltatheridia (Mellett and Szalay, 1968; Tang and Yan, 1976), Leptictida, Mesonychia (Lopatin, 1997), Condylarthra (Gingerich, 1981), Didymoconida (Lopatin, 2001; Morlo and Nagel, 2007), and Order indet. (Li et al., 1979; Meng, 1990). Here, we tentatively use Didymoconida as higher-level taxon.

Tang and Yan (1976) reported *Zeuctherium niteles* as a didymoconid on the basis of a partial skull. Missiaen et al. (2013) described another didymoconid *Archaeoryctes wangi* based on a pair of lower jaws. Huang and Zheng (2002) named *Wanolestes lii* based on a pair of incomplete lower jaws and referred *Wanolestes* to ?Micropternodontidae of Soricomorpha. Lopatin (2006) considered that *Wanolestes* is similar to *Archaeoryctes* and placed *Wanolestes* in Didymoconidae.

Zeuctherium and *Archaeoryctes wangi* were found from the lower part of the Upper Member of Wanghudun Formation at Zhangjiawu East and Zhongjialaowu, respectively. Both taxa are of the Early Paleocene Shanghuan ALMA. The specimens of *Wanolestes lii* were found from the Upper Member of Doumu Formation at Yangxiaowu, which is in the Middle Paleocene Nongshanian ALMA.

4.3.11 Order indet.

Several mammal species, named on the basis of Qianshan Paleocene materials, are not able to be assigned to a taxonomically higher group with certainty. They are listed here under indeterminate order.

Anchilestes impolitus was named by Chiu and Li (1977) based on incomplete left upper and lower jaws with P3–M2 and p4–m3 of the same individual. It was originally referred to Zalambdalestidae within Anagalida (Chiu and Li, 1977). Ting and Zheng (1989) reevaluated its affinity and assigned it to the order Tillodontia. However, the morphology of both the upper and lower dentitions of *Anchilestes* is distinct from those of tillodonts and zalambdalestids, providing little evidence to support a special relationship to either tillodonts or zalambdalestids

(Wang et al., 1998; Wang and Jin, 2004). *Anchilestes impolitus* was found from the Lower Member of Wanghudun Formation at Wangdawu, which is in the Early Paleocene Shanghuan ALMA.

Decoredon elongetus was reported on the basis of a left and a right lower jaws both with p4–m3, and originally referred to Hyopsodontidae within Condylarthra (Xu, 1977). Szalay and Li (1986) combined *Decoredon elongetus* with *Diacronus anhuiensis* into a single species, *Decoredon anhuiensis*. They considered *Decoredon anhuiensis* as a member of ?Omomyidae within Euprimates and named a new subfamily, Decoredontinae. This assignment has received little support and was considered to be questionable (Rose, 1994; Rose et al., 1994) or unlikely (Gingerich et al., 1991). Kondrashov and Lucas (2004b) considered that *Decoredon anhuiensis* did not exhibit features typical of either archaic ungulates or omomyid primates, but accepted the synonymy of *Diacronus anhuiensis* and *Decoredon elongetus*. As noted before, due to the conspecific assignment suspect of the holotypes (and only known specimens) of both taxa (Rose et al., 1994), it might better consider them as separate species and tentatively leave *Decoredon elongetus* as Order and Family incertae sedis at present. The specimens of *Decoredon elongetus* were collected from the lower part of the Upper Member of Wanghudun Formation at Zhangjiawu East (Xu, 1977), which suggest its occurrence in the Early Paleocene Shanghuan ALMA.

Obtususdon hanhuaensis was described by Xu (1977) based on a fragmentary right lower jaw with p4–m3 (holotype) and a fragmentary left lower jaw with p4–m3. Its taxonomic position was considered indeterminate and requires further study with the finding of some better specimens. The holotype was collected from the Lower Member of Doumu Formation at Hanhuawu South, which is in the Middle Paleocene Nongshanian ALMA. The referred specimen was found from the lower part of the Upper Member of Wanghudun Formation at Dingxiawu, which is of the Early Paleocene Shanghuan ALMA.

Wania chowi was based on two fragments of a left maxilla and a pair of lower jaws of the same individual (Wang, 1995). It was originally referred to the family Zhelestidae in the order Mixotheridia, but Nessov et al. (1998) argued that *Wania chowi* “is not a zhelestid but may have anagalidan affinities.” Because determination of its phylogenetic position requires further study, *Wania chowi* is temporarily classified as Order and Family indeterminate (Wang et al., 1998). The specimens of *Wania chowi* were collected from the lower part of the Upper Member of Wanghudun Formation, which is of the Early Paleocene Shanghuan ALMA.

5 Correlation and age determination

Of all the Chinese Paleocene basins, the Nanxiong, Qianshan, Chijiang, and Erlian (Nei Mongol) basins have yielded particularly important records of fossil mammals. The first three basins mainly produce fossil mammals spanning the Early–Middle Paleocene, while

the Erlian Basin documents relatively later Paleocene faunas. The records from these basins were used as a baseline in correlating the Chinese mammal-bearing Paleocene. On the basis of the mammalian fossil record then available, previous researchers proposed correlations of Paleocene strata within China. They considered that the Shanghu, Shizikou, and Wanghudun formations were correlatives and correlated the Nongshan Formation with the Chijiang and Doumu formations (South China "Redbeds" Research Group, 1977; Zheng and Qiu, 1979; Li and Ting, 1983; Ting, 1998; Ting et al., 2011). After careful review of the occurrence of fossil mammals in the Nanxiong, Qianshan, and Chijiang basins, Wang et al. (1998) tentatively correlated the boundary between the Shanghu and Nongshan formations (Nanxiong Basin) with that between the Shizikou and Chijiang formations (Chijiang Basin), and within the Upper Member of the Wanghudun Formation (Qianshan Basin). The mammalian faunas from strata below this boundary are dominated by *Bemalambda*, while faunas from strata above the boundary are characterized by the co-occurrence of *Archaeolambda* and *Altilambda*, without *Bemalambda* (Fig. 2). Such a correlation first appeared in Wang's (1993) Ph.D. dissertation and was in accordance with Tong et al.'s (1995) opinion.

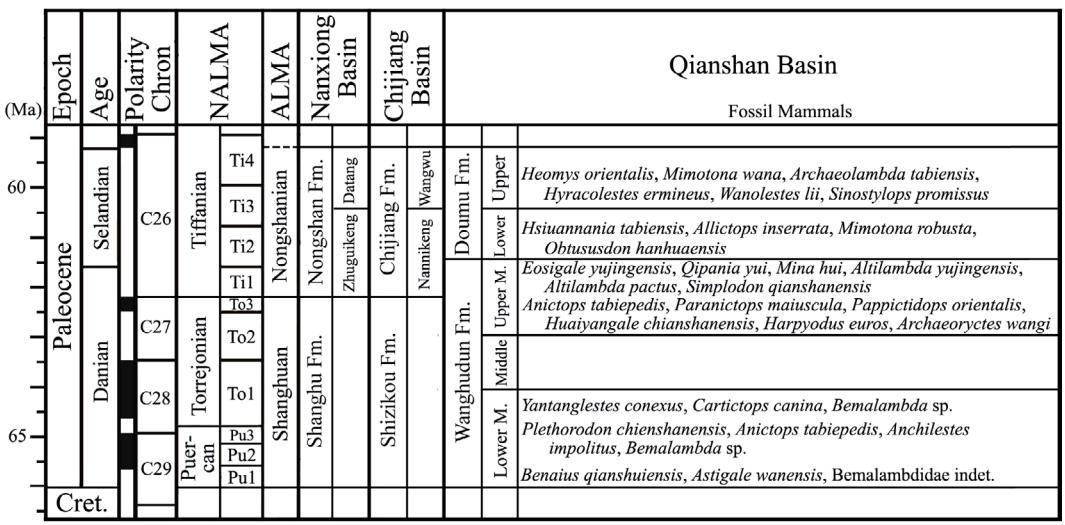

Fig. 2 Correlation of the Paleocene in the Qianshan Basin with that in the Nanxiong and Chijiang basins, and with Geological Time Scale and NALMAs
Polarity Chrons and NALMAs are modified from Vandenberghe et al. (2012)

Like in other Chinese Paleocene basins, great endemism of mammalian fauna hampered the intercontinental biostratigraphic correlation of the Qianshan Paleocene. No radiometric dates and failed attempt of paleomagnetic study further obstruct to correlate the Paleocene in the Qianshan Basin directly to the Global Geologic Timescale. The age determination of the Qianshan Paleocene mammalian fauna and fossil-bearing strata relies on the biostratigraphic correlation with other Paleocene basins, where the Paleocene could be correlated to those of other continents or the Timescale by certain means.

Early biostratigraphic studies considered mammalian faunas known from the Shanghu, Shizikou, and Wanghudun formations and their correlatives to represent the Early–Middle Paleocene, while those from the Nongshan, Chijiang, Doumu, as well as Nomogen (Erlian Basin) formations and their correlatives were considered as Late Paleocene (South China "Red Beds" Research Group, 1977; Zheng and Qiu, 1979; Chow and Zheng, 1980; Li and Ting, 1983; Russell and Zhai, 1987). Li and Ting (1983) proposed two provincial mammal ages, the Shanghuan and the Nongshanian, to represent the Early–Middle and Late Paleocene respectively in correlation with Europe and North America. They tentatively correlated the Shanghuan with the North American Puercan and Torrejonian and the Nongshanian (including present Gashatan) with the North American Tiffanian in their correlation chart. Sloan (1987) followed the use of two mammal ages, but favored Gashatan over Nongshanian as a stage (age) name for the Asian Late Paleocene on the basis of priority of the former. He correlated the Shanghuan with the Torrejonian and part of the Tiffanian (To1–Ti4), and considered the Gashatan (=Nongshanian of Li and Ting, 1983) to be the late Tiffanian–Clarkforkian (Ti5–Cf3) equivalent. Tong et al. (1995) continued to use the Shanghuan and Nongshanian (the latter including some Gashatan correlatives) as Early and Late Paleocene provincial mammal ages of China. They correlated the Shanghuan with North American Puercan and early–middle Torrejonian, and the Nongshanian with the late Torrejonian through Clarkforkian in their correlation chart. In the same year, Lucas and Williamson (1995) proposed a correlation of the Shanghuan with the North American Puercan, based on their comparison of the evolutionary stages of certain mammal taxa, including Mesonychidae, Carnivora, Tillodontia, and Pantodonta, but Wang et al. (1998) disagreed with their opinion. Both Wang et al. (1998) and Ting (1998) used three ages to represent Chinese Paleocene: the Shanghuan, the Nongshanian and the Gashatan, but their correlation with North American Land Mammal Ages were slightly different. Ting (1998) correlated the Shanghuan, Nongshanian and Gashatan with Torrejonian, Tiffanian and Clarkforkian, respectively, while Wang et al. (1998) considered the three Chinese mammal ages to be respectively correlative with Puercan through middle Torrejonian (Pu1–To2), late Torrejonian through middle Tiffanian (To3–Ti4) and late Tiffanian through Clarkforkian (Ti5–Cf3).

Recent paleomagnetic results from the Nanxiong Basin indicate that the boundary between the Shanghu Formation and the underlying Pingling Formation lies within the upper half of Chron C29R, consistent with all the other precisely constrained K/Pg boundaries in the world (Clyde et al., 2010). Paleomagnetic results from both the Chijiang and Nanxiong basins clearly show that the Shanghuan is Early Paleocene in age (Danian) and corresponds to North American Puercan and Torrejonian. The placement of the Shanghuan/Nongshanian boundary near the top of Chron C27N implies that it is synchronous with the Torrejonian/Tiffanian boundary (Clyde et al., 2008; 2010). In combination with those from the Erlian Basin (Sun et al., 2009), the paleomagnetic results indicate that the Nongshanian/Gashatan boundary lies somewhere between the upper part of Chron C26R and Chron C26N, corresponding to the

upper part of the Tiffanian. Therefore, the Shanghuan and the Nongshanian can be probably correlated to the Early Paleocene Danian and the Middle Paleocene Selandian of the Global Geologic Time Scale (Vandenberghe et al., 2012). Such a correlation shows that both the Wanghudun and Doumu formations and fossil vertebrates therefrom are the Early and Middle Paleocene in age.

6 Concluding remarks

The Mesozoic and Cenozoic redbeds in the Qianshan Basin consist of a set of monocline clastic rocks, and are subdivided into the Late Cretaceous Gaohebu Formation, the Paleocene Wanghudun and Doumu formations. The Wanghudun Formation is further subdivided into the Lower, Middle, and Upper members, while the Doumu Formation falls into the Lower and Upper members.

Continuous investigations in the Qianshan Basin resulted in discovery of a lot of vertebrate specimens. Sixty one species (including 9 unnamed ones) in 45 genera of vertebrates, representing reptiles, birds and mammals, have been reported from the Paleocene of the Qianshan Basin. Among them, mammals are most diverse and have been classified into 46 species (7 unnamed) of 33 genera, representing 16 families in 10 orders. According to the stratigraphic distribution of fossil vertebrates, 7 fossiliferous horizons can be recognized in the Qianshan Paleocene: 1) The basal part of the Lower Member of Wanghudun Formation; 2) the middle part of the Lower Member of Wanghudun Formation; 3) the upper part of the Lower Member of Wanghudun Formation; 4) the lower part of the Upper Member of Wanghudun Formation; 5) the upper part of the Upper Member of Wanghudun Formation; 6) the Lower Member of Doumu Formation; and 7) the Upper Member of Doumu Formation.

Based on the evidence of fossil mammals, the strata from the Lower Member through the lower part of the Upper Member of Wanghudun Formation could be roughly correlated to the Shanghu Formation of the Nanxiong Basin and the Shizikou Formation of the Chijiang Basin, corresponding to the Shanghuan ALMA. Both the upper part of the Upper Member of Wanghudun Formation and the Doumu Formation could be correlated to the Nongshan Formation of the Nanxiong Basin and the Chijiang Formation of the Chijiang Basin, corresponding to the Nongshanian ALMA. Paleomagnetic results from both the Chijiang and Nanxiong basins suggest that the Shanghuan is roughly correlative to the Puercan and Torrejonian NALMA, while the Nongshanian correlative to the early to middle Tiffanian (Ti1–4a). The Shanghuan and the Nongshanian can be probably correlated to the Early Paleocene Danian and the Middle Paleocene Selandian of the Global Geologic Time Scale.

Acknowledgments We are grateful to Yu Ben'ai, Chen Limin, Li Tao, Yu Shuhua, Xiong Yuansheng and Xu Yiping of the Qianshan County Museum, Wang Zongwu, Xu Lizhi, Deng Guolai and Zhou Min of the Bureau of Cultural Relics of Qianshan County, Yu Guosheng and

Cheng Xiaoqing of the Tianzhushan Global Geopark, and Xie Shuhua, Zhou Xiaoyuan, Zhou Wei, Bai Bin, Gao Wei, Li Shijie, Li Qi and Wang Yongxing of IVPP for their assistance in the field. This work was supported by the Major Basic Research Projects of MST of China (No. 2012CB821900), the National Natural Science Foundation of China (Nos. 41572013, 41572021) and the Conservation Program of the Geological Heritage Sites of the Ministry of Finance and the Ministry of Land and Resources, People's Republic of China.

安徽潜山盆地古新世地层和脊椎动物概述

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摘要：潜山盆地中、新生代红层由一套单斜的碎屑岩组成，划分为上白垩统高河埠组、古新统望虎墩组(分为上、中、下三段)和痘姆组(分上、下两段)。1970年以来，在潜山盆地的持续调查发现了大量脊椎动物化石。迄今为止，潜山盆地古新统共报道了45属61种(含9个未命名的种)脊椎动物，包括爬行类、鸟类和哺乳类。其中哺乳动物最为丰富，共有33属46种(含7个未命名种), 分属10个目16个科。根据化石产出的层位，可以在潜山古新统中识别出7个化石层位。基于哺乳动物生物地层学证据，望虎墩组下段至上段下部可以大致与广东南雄盆地上湖组和江西池江盆地狮子口组对比，对应于亚洲陆相哺乳动物分期的上湖期；望虎墩组上段上部和痘姆组可以与南雄盆地浓山组以及池江盆地的池江组对比，与浓山期相对应。综合我国几个古新世盆地的古地磁研究结果显示，上湖期可以大致与北美陆相哺乳动物分期的Puercan和Torrejonian对比，浓山期则与Tiffanian早中期(Ti1–Ti4a)相当。上湖期和浓山期还可以进一步与国际地质年表中的丹尼期(Danian)和塞兰特期(Selandian)对比。因此，潜山盆地发现的脊椎动物化石的时代属于早、中古新世。

关键词：安徽潜山，古新世，脊椎动物，地层，对比

中图法分类号：Q915.873, P534.612 **文献标识码**：A **文章编号**：1000–3118(2016)02–0089–32

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Appendix 1 Faunal list of Paleocene vertebrates in the Qianshan Basin

In the bracket behind the taxa, 1.1 refers to the Lower Member of the Wanghudun Formation, 1.3a refers to the lower part of the Upper Member of the Wanghudun Formation, 1.3b refers to the upper part of the Upper Member of the Wanghudun Formation, 2.1 refers to the Lower Member of Doumu Formation, and 2.2 refers to the Upper Member of the Doumu Formation.

Reptilia Laurenti, 1768
- Testudines Linnaeus, 1758
  - Cryptodira Cope, 1868
    - Testudinoidea Batsch, 1788
      - *Anhuichelys* Yeh, 1979
        - *A. siaoshihensis* Yeh, 1979 (1.1, 1.3a)
        - *A. tsienshanensis* Yeh, 1979 (1.3b, 2.1, 2.2)
        - *A. doumuensis* Tong, Li, Li, Chen, Li, Yu, Yu, Cheng, Di & Claude, 2016 (2.2)
        - *Anhuichelys* sp. (1.3b, 2.1?)
- Squamata Oppel, 1811
  - Iguania Cope, 1864
    - Acrodonta Cope, 1864
      - *Agama* Daudin, 1802
        - *A. sinensis* Hou, 1974 (nomen dubium) (2.1)
      - *Anhuisaurus* Hou, 1974
        - *A. huainanensis* Hou, 1974 (2.2)
      - *Qianshanosaurus* Hou, 1974
        - *Q. huangpuensis* Hou, 1974 (1.1, 1.3a)
      - *Tinosaurus* Marsh, 1872
        - *T. doumuensis* Hou, 1974 (2.2)
  - Anguimorpha Fürbringer, 1900
    - Varaniformes Conrad, 2008
      - Gen. et sp. indet. (2.2)
  - Squamata incertae sedis
    - *Anqingosaurus* Hou, 1976
      - *A. brevicephalus* Hou, 1976 (1.1)
    - *Changjiangosaurus* Hou, 1976

C. huananensis Hou, 1976	(1.1)
Crocodilia Gmelin, 1788	
Wanosuchidae Zhang, 1981	
Wanosuchus Zhang, 1981	
W. atresus Zhang, 1981	(?)
Alligatoridae Gray, 1844	
Alligatorinae Gray, 1844	
Eoalligator Young, 1964	
E. huiningensis Young, 1982	(1.1)
Aves Linnaeus, 1758	
Gruiforms Coues, 1884	
Rallidae Vigors, 1825	
Wanshuina Hou, 1994	
W. lii Hou, 1994	(2.2)
Order indet.	
Qianshanornithidae Mayr, Yang, De Bast, Li & Smith, 2013	
Qianshanornis Mayr, Yang, De Bast, Li & Smith, 2013	
Q. rapax Mayr, Yang, De Bast, Li & Smith, 2013	(1.3a)
Mammalia Linnaeus, 1758	
Anagalida Szalay & McKenna, 1971	
Anagalidae Simpson, 1931	
Huaiyangale Xu, 1976	
H. chianshanensis Xu, 1976	(1.3a)
Huaiyangale sp.	(1.3a)
Hsiuannania Xu, 1976	
H. tabiensis Xu, 1976	(2.1)
Hsiuannania sp.	(2.2)
Eosigale Hu, 1993	
E. gujingensis Hu, 1993	(1.3b)
Qipania Hu, 1993	
Q. yui Hu, 1993	(1.3b)
?Anagalidae Simpson, 1931	
Diacronus Xu, 1976	
D. wanghuensis Xu, 1976	(1.3a)
D. anhuiensis Xu, 1976	(1.3a)
Anaptogale Xu, 1976	
A. wanghoensis Xu, 1976	(1.1)
Pseudictopidae Sulimski, 1968	
Anictops Qiu, 1977	
A. tabiepedis Qiu, 1977	(1.3a)
Anictops aff. *A. tabiepedis* Qiu, 1977	(1.3a)
A. wanghudunensis Zheng, Zheng & Huang, 1999	(1.3a, 1.1)
Paranictops Qiu, 1977	
P. majuscula Qiu, 1977	(1.3a)
Paranictops aff. *P. majuscule* Qiu, 1977	(1.3a)
Paranictops sp.	(1.1)
Allictops Qiu, 1977	
A. inserrata Qiu, 1977	(2.1)

Cartictops Ding & Tong, 1979
C. canina Ding & Tong, 1979 (1.1)
Astigalidae Zhang & Tong, 1981
Astigale Zhang & Tong, 1981
A. wanensis Zhang & Tong, 1981 (1.1)
Chianshania Xu, 1976
C. gianghuaiensis Xu, 1976 (1.1)
Family indet.
Wanogale Xu, 1976
W. hodungensis Xu, 1976 (1.1)
Simplicidentata Weber, 1904
Eurymylidae Matthew, Granger & Simpson, 1929
Heomys Li, 1977
H. orientalis Li, 1977 (2.2)
Heomys sp. (1.3a)
Duplicidentata Illiger, 1811
Mimotonida Li, Wilson, Dawson & Krishtalka, 1987
Mimotonidae Li, 1977
Mimotona Li, 1977
M. wana Li, 1977 (1.3a?, 2.2)
M. robusta Li, 1977 (2.1)
M. lii Dashzeveg & Russell, 1988 (1.3a)
Mimolagidae Szalay, 1985
Mina Li, Wang, Zhang, Mao & Meng, 2016
M. hui Li, Wang, Zhang, Mao & Meng, 2016 (1.3b)
Didymoconida Lopatin, 2001
Didymoconidae Kretzoi, 1943
Zeuctherium Tang & Yan, 1976
Z. niteles Tang & Yan, 1976 (1.3a)
Archaeoryctes Zheng, 1979
A. wangi Missiaen, Solé, De Bast, Yan, Li & Smith, 2013 (1.3a)
Wanolestes Huang & Zheng, 2002
W. lii Huang & Zheng, 2002 (2.2)
Carnivora Bowdich, 1821
Viverravidae Wortman & Matthew, 1899
Pappictidops Chiu & Li, 1977
P. orientalis Chiu & Li, 1977 (1.3a)
Mesonychia Matthew, 1937
Mesonychidae Cope, 1875
Yantanglestes Ideker & Yan, 1980
Y. conexus (Yan & Tang, 1976) (1.1)
Pantodonta Cope, 1873
Bemalambdidae Chow, Zhang, Wang & Ding, 1973
Bemalambdidae gen. et sp. indet. (1.1)
Bemalambda Chow, Zhang, Wang & Ding, 1973
Bemalambda sp. (1.1)
Harpyodidae Wang, 1979
Harpyodus Qiu & Li, 1977
H. euros Qiu & Li, 1977 (1.3a)

Pantolambdodontidae Granger & Gregory, 1934	
Archaeolambda Flerov, 1952	
A. tabiensis Huang, 1977	(2.2)
Pastralodontidae Chow & Qi, 1978	
Altilambda Chow & Wang, 1978	
A. pactus Chow & Wang, 1978	(1.3?)
A. yujingensis Wang, Yu & Li, 1992	(1.3b?)
?*A. tenuis* Chow & Wang, 1978	(1.3a)
Arctostylopida Cifelli, Schaff & McKennna, 1989	
Arctostylopidae Schlosser, 1923	
Sinostylops Tang & Yan, 1976	
S. promissus Tang & Yan, 1976	(2.2)
Tillodontia Marsh, 1875	
Plethorodontidae Huang & Zheng, 1987	
Plethorodon Huang & Zheng, 1987	
P. chienshanensis Huang & Zheng, 1987	(1.1)
Family indet.	
Simplodon Huang & Zheng, 2003	
S. qianshanensis Huang & Zheng, 2003	(1.3b)
Benaius Wang & Jin, 2004	
B. qianshuiensis Wang & Jin, 2004	(1.1)
Cimolesta McKenna, 1975	
Sarcodontidae Lopatin & Kondrashov, 2004	
Hyracolestes Matthew & Granger, 1925	
H. ermineus Matthew & Granger, 1925	(2.2)
Order indet.	
Family indet.	
Wania Wang, 1995	
W. chowi Wang, 1995	(1.3a)
Obtususdon Xu, 1977	
O. hanhuaensis Xu, 1977	(2.1, 1.3a)
Decoredon Xu, 1977	
D. elongetus Xu, 1977	(1.3a)
Anchilestes Chiu & Li, 1977	
A. impolitus Chiu & Li, 1977	(1.1)